

The background of the slide is a high-resolution image of the Mars surface, showing a reddish-brown terrain with numerous impact craters of various sizes, some with distinct rims and shadows. The lighting creates a sense of depth and texture across the landscape.

Mars Missions Using Emerging *Commercial Space Transportation* Capabilities

**ISU 2016 Summer Session
Implications of New Discoveries in the
Martian Environment – Commercial
Transportation Options
Technion, Haifa, Israel
Ver. 5.0 July 2016**

Andrew A. Gonzales
*Senior Systems Engineer, NASA, Ames Research Center
Mission Design Division
With over 20 years experience in advanced mission design*

Team Project 2, Task 5, Mars Missions

Resource Modules Abstract -1

- New Discoveries regarding the Martian Environment may impact Mars mission planning. Transportation of investigation payloads can be facilitated by Commercial Space Transportation options. The development of Commercial Space Transportation. Capabilities anticipated from various commercial entities are examined objectively. The potential for one of these options, in the form of a Mars Sample Return mission, described in the results of previous work, is presented to demonstrate a high capability potential. The transportation needs of the Mars Environment Team Project at ISU 2016 may fit within the payload capabilities of a Mars Sample Return mission, but the payload elements may or may not differ.

Disclaimer: *The work described in these Resource Modules was performed internally using information in the public domain and without the assistance of any commercial organization. There is no endorsement of any particular commercial organization by NASA. There is also no endorsement of this work by any particular commercial organization. Any opinions expressed are the those of the Team Project Resource Module presenter.*

Team Project 2, Task 5, Mars Missions

Resource Modules Abstract - 2

- Resource Modules will help you develop a component of a strategy to address the Implications of New Discoveries in the Martian Environment – using the possibility of efficient, commercial space transportation options
- Opportunities for open discussions as appropriate during the team project formulation period – at the end of each Resource Module
- The objective is to provide information that can be incorporated into your work in the Team Project– including brainstorming

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Team Project 2, Task 5, Mars Missions

Resource Modules Overview

Definition of *Commercial Space Transportation* for purposes of these resource modules:

- ✓ *An arrangement by which a private company uses a spacecraft that they have developed internally in order to provide cargo and/or crew space transportation services on a “fee for service” basis.*
- X *As opposed to an arrangement by which a private company builds a spacecraft based on specifications from a government customer, and provides operational support to that government customer. The Space Shuttle was in this category and Orion will be in this category.*

Team Project 2, Task 5, Mars Missions

Resource Modules Overview

- Resource Module 1 – International capabilities are in place, but *Commercial Space Transportation* capabilities are also emerging to meet NASA's cargo and crew transportation to the ISS in LEO.
- Resource Module 2 - Some private companies are working on systems to provide space transportation beyond LEO
 - May or may not meet our definition of *Commercial Space Transportation*
 - Possibly to achieve their own goals
- Resource Module 3 (extended time) - Ultimately one or more private company's vehicle may become available to provide Space Transportation services to Mars.
 - Could support missions in support of hazard location – there will time to brainstorm possibilities
 - Could support missions that utilize in-situ resources – there will time to brainstorm possibilities
 - Could also advance technology for larger, human mission scale landers

The background of the slide is a high-resolution image of the Martian surface, showing a reddish-brown terrain with numerous impact craters of various sizes. The lighting creates shadows that emphasize the ruggedness of the landscape.

Resource Module 1 – Emerging *Commercial Space Transportation* Capabilities - LEO

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ISS Cargo – International Capabilities

- NASA has cargo transportation needs to support the ISS in LEO
- Current International Capabilities for cargo delivery to ISS :
 - Russian Progress / Soyuz – ongoing program with updates
 - Up mass only, plus waste disposal via re-entry incineration
 - Pressurized cargo
 - European ATV / Ariane 5 – program completed
 - Up mass only, plus waste disposal via re-entry incineration.
 - Pressurized and unpressurized cargo.
 - Japanese Kounotori HTV / H-II – ongoing program
 - Up mass only, plus waste disposal via re-entry incineration.
 - Pressurized and unpressurized cargo.
- Each delivery was or will be “fee for service” but not by a private company provider. “Fee” may be “in-kind” services.

ISS Crew – International Capabilities

- NASA also has crew transportation needs to support the ISS in LEO
- Current International Capabilities for crew delivery to ISS:
 - Russia's Soyuz – ongoing program
- Each delivery was or will be “fee for service” but not by a private company provider. “Fee” in this case is currency.



NASA Commercial Orbital Transportation Services (COTS)

Commercial Space Transportation

- In 2004, U.S. decision made to retire the Space Shuttle at end of 2010 after completion of the ISS.
- In 2005, NASA challenged U.S. private industry to develop cargo and crew space transportation capabilities that could meet the needs of ISS in LEO.
- NASA allocated \$500 million over five years to stimulate the development and demonstration of commercial capabilities
- A portfolio of multiple partners with different capabilities assured a balanced approach to technical and business risks
- Increased the chances of at least one successful partner
- Market forces kept development and operational costs in check

US Mail Air Transport Precedent

- In 1925 the US Kelly Act, mandated that the US Post Office contract air mail routes to independent companies.
- It was anticipated that airlines would reinvest profits earned from carrying air mail into establishing passenger services.
- By 1929, there were 44 separate companies flying 53 different routes.
- There were consolidations, and some political issues.
- After a brief, unsuccessful use of US Army Aviation, in 1934, commercial carriers successfully continued the mail service.
- Commercial aviation industry prospered, built a customer base and developed passenger service.
- Each delivery was “fee for service” by a private company provider



A wide-angle photograph of the Martian surface, showing a vast, flat, reddish-brown landscape with low, rolling hills in the distance under a hazy, orange-tinted sky.

Commercial Definition Review

- ✓ *An arrangement by which a private company uses an aircraft that they have obtained in order to provide mail transportation services on a “fee for service” basis.*

Emergence of *Commercial Space Transportation* of Cargo Capabilities

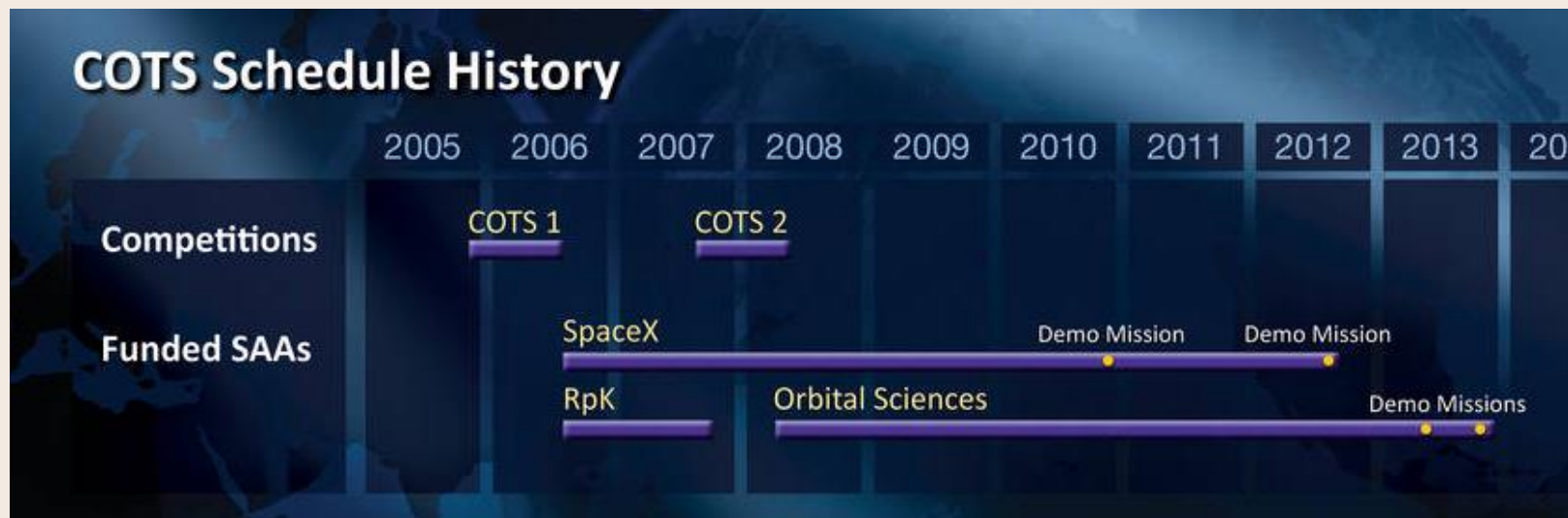
- Current and future, commercial capabilities for ISS cargo deliveries:
 - SpaceX Dragon / Falcon 9 - program in operation
 - Up and down mass
 - Pressurized and unpressurized cargo.
 - Orbital Cygnus / Antares or Atlas V – program in operation
 - Up mass only, plus waste disposal via re-entry
 - Sierra Nevada Dream Chaser / Atlas V or Ariane V (ESA also building docking adapter) – not yet operational,
 - Up and down mass
 - Pressurized and unpressurized modules
- Each delivery has been or will be “fee for service” by a private company provider



COTS Summary to Date

- Many successes, but also a few failures
- The COTS model is working
 - Implements U.S. Space Exploration policy with investments to stimulate the commercial space industry
 - Facilitates U.S. private industry demonstration of cargo and crew space transportation capabilities with the goal of achieving safe, reliable, cost effective access to low-Earth orbit
 - Creates a market environment in which commercial space transportation services are available to Government and private sector customers
- NASA's Commercial Crew and Cargo Program will extend human presence in space by enabling an expanding and robust U.S. commercial space transportation industry.

Early Schedule



A background image of a Mars landscape with rolling hills and a hazy orange sky.

Emergence of *Commercial Space Transportation* of Crew Capabilities

- Future Commercial Capabilities for crew delivery to ISS:
 - SpaceX Dragon / Falcon 9 – expected operational in 2017
 - Boeing CST-100 Starliner / Atlas V – expected operational in 2017
- Each system is “fee for service”

Why important – how is this related to Mars

- Discussion of emergence of commercial capabilities shows the progress being made towards:
 - Extending human presence in Space using industry to provide services for capabilities that NASA has retired
 - Establishes Multiple capabilities to provide redundancy and a broader selection of services
- Industry is establishing the infrastructure and confidence to foster exploration, expand commercial operations in LEO, and push boundaries out beyond LEO

Open Discussion

- Have we left anyone out?
 - Are there other private companies that need to be discussed?
 - Are there other government organizations that consider themselves to be similar to a company?
- How will private customers participate?
 - Industrial activities
 - Tourism

Open Discussion (cont.)

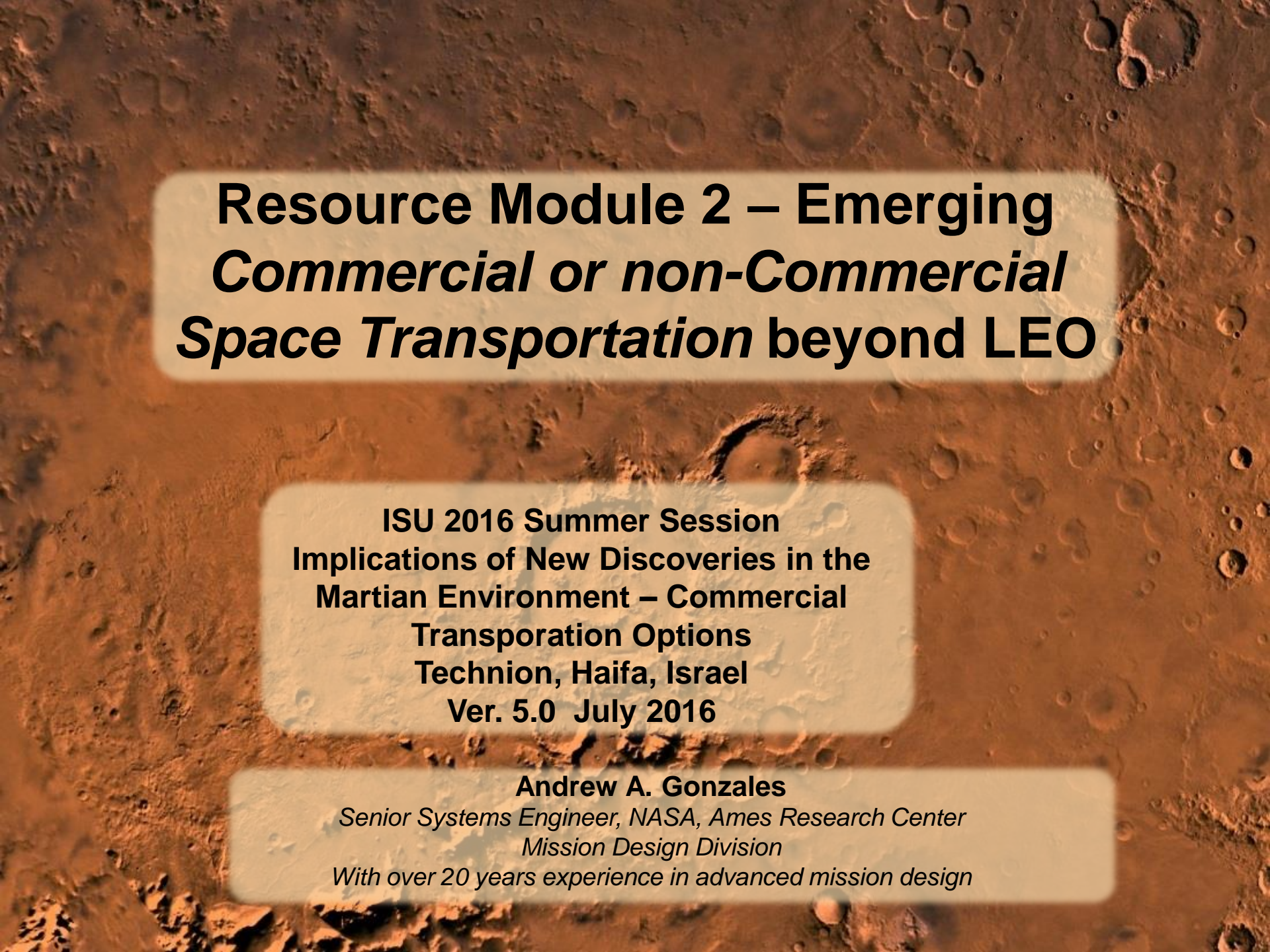
- Your perception of space commerce
 - How has it worked so far?
 - Where do you see it going within the span of your careers?
 - Are you interested in becoming actively involved in Space Commerce?

Additional Reading

Progress	<u>http://spaceflight101.com/spacecraft/progress-m/</u>
Soyuz	<u>http://spaceflight101.com/spacecraft/soyuz-tma-m/</u>
ATV	<u>http://spaceflight101.com/spacecraft/ATV/</u>
HTV	<u>http://spaceflight101.com/spacecraft/htv-spacecraft-information/</u>
Cygnus	<u>http://spaceflight101.com/spacecraft/Cygnus/</u>
Dragon	<u>http://www.spacex.com/news/2014/05/30/dragon-v2-spacexs-next-generation-manned-spacecraft</u>
Starliner (CST-100)	<u>http://www.boeing.com/space/crew-space-transportation-100-vehicle/index.page</u>
Dream Chaser	<u>http://www.sncspace.com/ProductLines/SpaceExplorationSystems</u>
C3PO	<u>http://www.nasa.gov/offices/c3po/home/#.VsZ38kZUiKI</u>

Resource Module 2 - Preview

- Continuation of Open Discussion if additional time is needed
- Some private companies are working on systems to provide space transportation beyond LEO
 - May or may not meet our definition of *Commercial Space Transportation*
 - Possibly to achieve their own goals

The background of the slide is a high-resolution image of the Martian surface, showing a reddish-brown terrain with numerous impact craters of various sizes and some darker, possibly mineral-rich, patches.

Resource Module 2 – Emerging *Commercial or non-Commercial* Space Transportation beyond LEO

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Resource Module 2 - Introduction

- Continuation of Open Discussion if additional time is required
- Some private companies are working on systems to provide space transportation beyond LEO
 - May or may not meet our definition of *Commercial Space Transportation*
 - Possibly to achieve their own goals

Commercial Transportation to the Moon or to Mars

- Review of the players discussed in Resource Module 1
 - SpaceX commercial – Dragon launched by Falcon 9 / Falcon Heavy,
 - Boeing commercial – Starliner launched by Atlas V
 - Sierra Nevada commercial – Dream Chaser launched by Atlas V
- Addition of other players and vehicles / systems
 - Boeing non-commercial – Prime contractor for the Space Launch System (SLS)
 - Lockheed Martin non-commercial – Prime contractor for Orion launched by SLS

SpaceX Aspirations Beyond LEO

- The Moon
 - SpaceX has not expressed an interest in the moon, Dragon is optimized for an atmospheric entry.
 - ✓ As will be seen later, augmentation by retro propulsion is possible.
 - ✓ Re optimization, i.e. heat shield removal, thruster reconfiguration, etc., for the moon would actually result in a new vehicle
 - SpaceX has a contract to provide launch services to Google X-prize contestant Spacell, from Israel, as brokered through Spaceflight Services.

SpaceX Aspirations Beyond LEO (cont.)

- Mars
 - SpaceX has expressed an interest in Mars many times, Dragon is optimized for an atmospheric entry and a landing on land.
 - ✓ As will be seen later, augmentation by retro propulsion is possible.
 - ✓ Studies within NASA and statements from Elon Musk support this

<http://www.businessinsider.com/about-nasas-red-dragon-project-2015-9>

Elon Musk

✓ @elonmusk

Dragon 2 is designed to land on any surface (liquid or solid) in the solar system.
Am glad to see people thinking about applications! 9/14/2015

<http://money.cnn.com/2016/01/30/news/companies/spacex-elon-musk-mars-2025/>

Boeing Aspirations Beyond LEO

- The Moon
 - Boeing is not directly working on Lunar exploration.
 - Contractor for SLS, more Mars focused
 - Cis-lunar habitats
 - No use of Starliner

Boeing Aspirations Beyond LEO (cont.)

- Mars
 - Boeing is working on support systems for Mars exploration.
 - Contractor for SLS, which is Mars focused
 - Technologies
 - No use of Starliner

Sierra Nevada Aspirations Beyond LEO

- The Moon
 - Sierra Nevada is not directly working on Lunar exploration.
 - No use of Dream Chaser

Sierra Nevada Aspirations Beyond LEO (cont.)

- Mars
 - Sierra Nevada builds motor and actuator components for robotic Mars missions
 - No use of Dream Chaser



Other Interested Party - Bigelow Aerospace

- Inflatable Habitat Module
 - Bigelow Expandable Activity Module (BEAM) experimental program at ISS
 - BA330 independent module
- Inflatable Lunar Habitation Module
- Inflatable in-space habitat – Mars Transit

Open Discussion

- There are companies who are positioning themselves to supply equipment and services in space applications.
- Do these possible activities conform to an extension of our Definition of *Commercial Space Transportation*?

Updated Definition of *Commercial Space Services*

An arrangement by which a private company uses equipment or intellectual property that they have developed internally in order to provide space services on a “fee for service” basis.

Additional Reading


SpaceX	<u>http://money.cnn.com/2016/01/30/news/companies/spacex-elon-musk-mars-2025/</u>
Boeing	<u>https://www.nasaspaceflight.com/2013/01/boeing-outlines-technology-crewed-mars-missions/</u>
Sierra Nevada	<u>http://www.sncorp.com/</u>
Bigelow	<u>http://bigelow aerospace.com/</u>

Resource Module 3 - Preview

- SpaceX appears to have the broadest Mars aspirations
- We will look at Red Dragon as a Mars Cargo Delivery Vehicle,

Disclaimer: We are not picking a winner.

- An assessment of the SpaceX Dragon capsule in its expression as Red Dragon
 - A look at some examples from recent Red Dragon studies and publications
 - What has SpaceX done to enable Red Dragon
- How could Red Dragon be used:
 - Could support missions in support of hazard location – there will time to brainstorm possibility
 - Could support missions that utilize in-situ resources – there will time to brainstorm possibility
 - Could also advance technology for larger, human mission scale landers

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Resource Module 3 - Red Dragon – a Mars Cargo Delivery Vehicle

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Resource Module 3 – Time Allocations

- During the first 45 minutes, the Red Dragon concept will be discussed with mission examples.
- After a 5 minute break, there will be a 30 minutes brainstorming session for possibilities within the scope of Team Project 2 – how can relevant hardware be best delivered and deployed.
- The final 10 minutes will be a wrap-up with the possibility of further discussion outside of the formal Resource Module.

Resource Module 3 - Introduction

- SpaceX appears to have the broadest Mars aspirations
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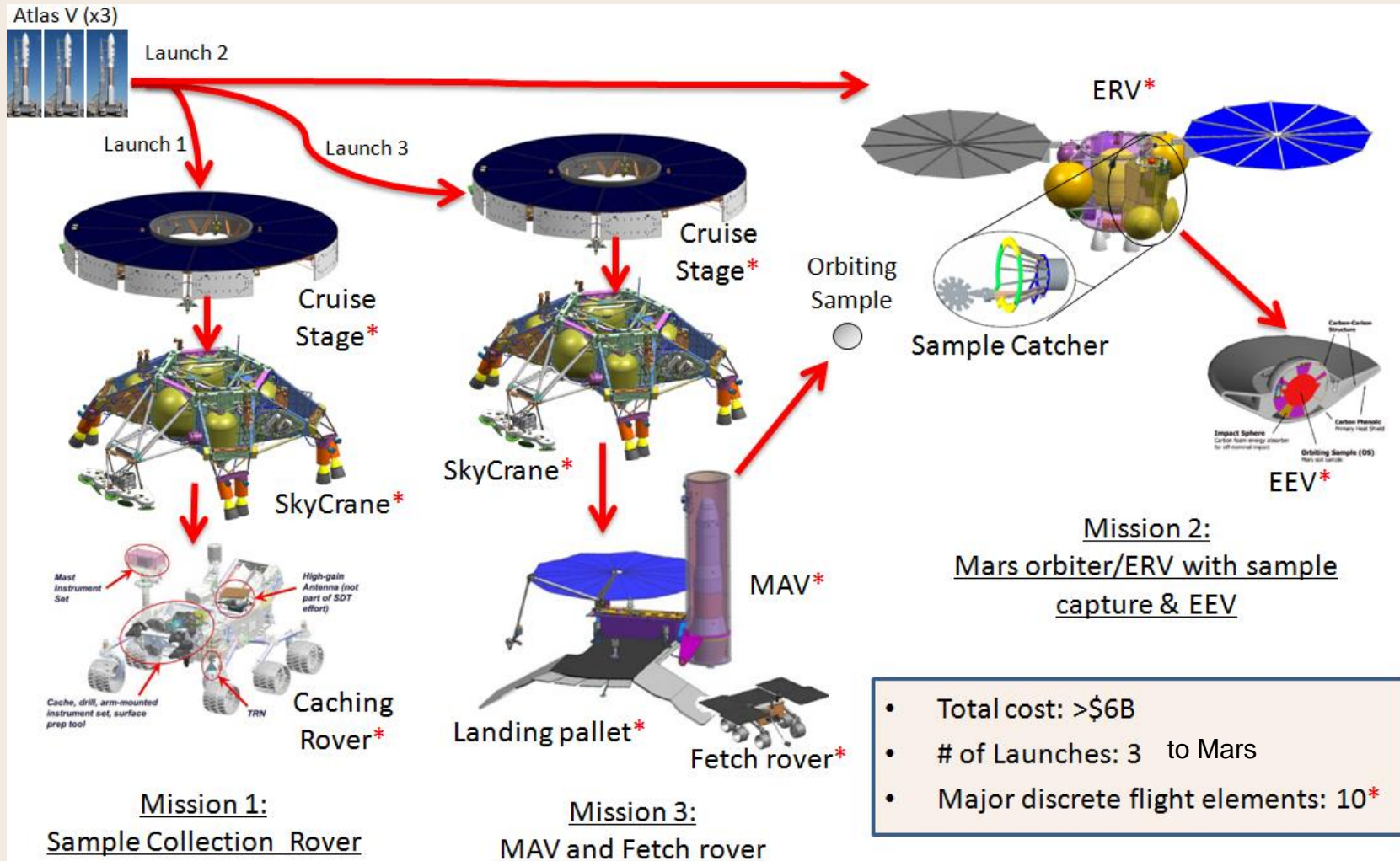
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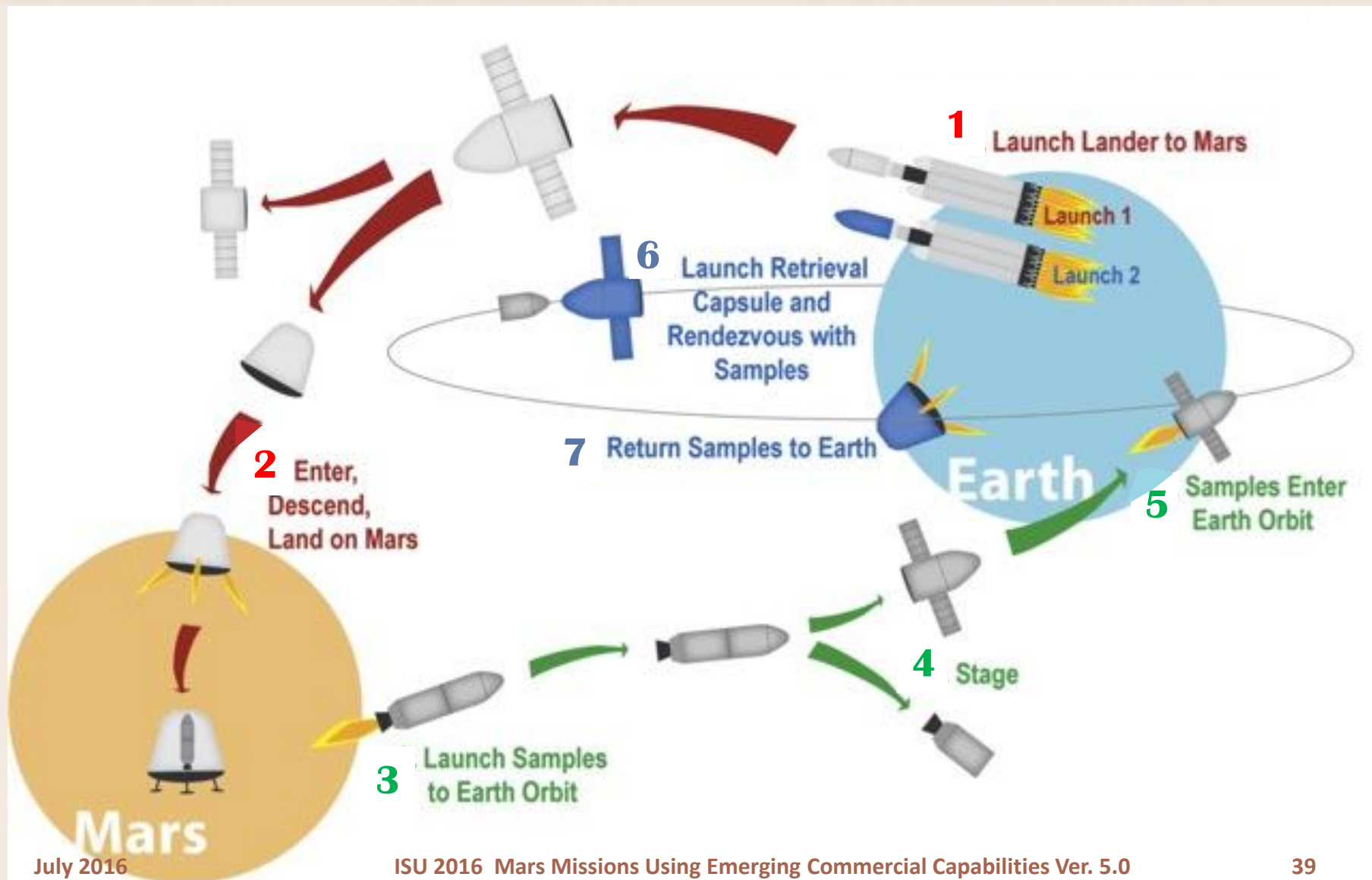


Mars Sample Return Mission Concept Example

Decadal Survey Mars Sample Return Example



Red Dragon MSR Architecture Description

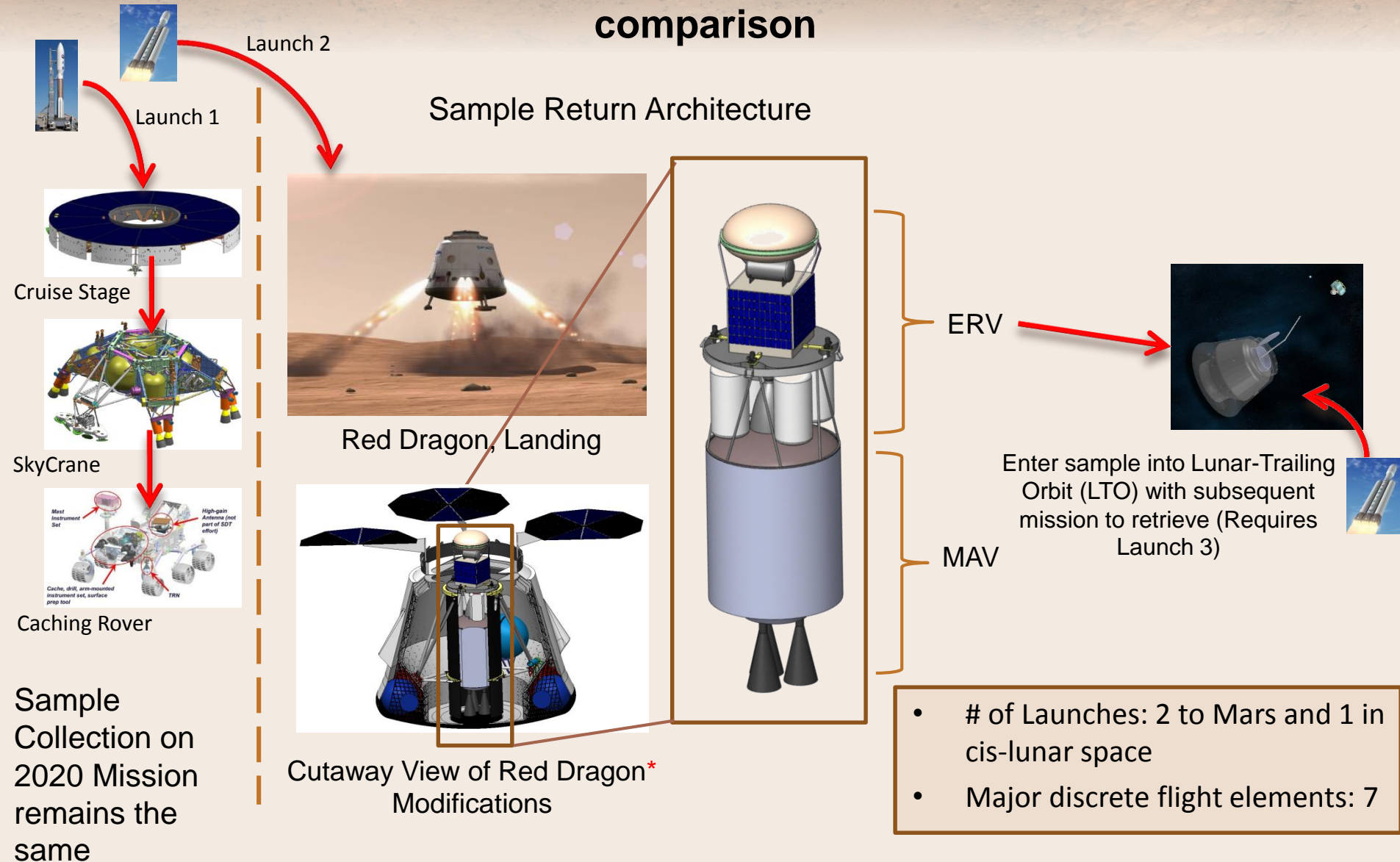


Red Dragon MSR Architecture Description

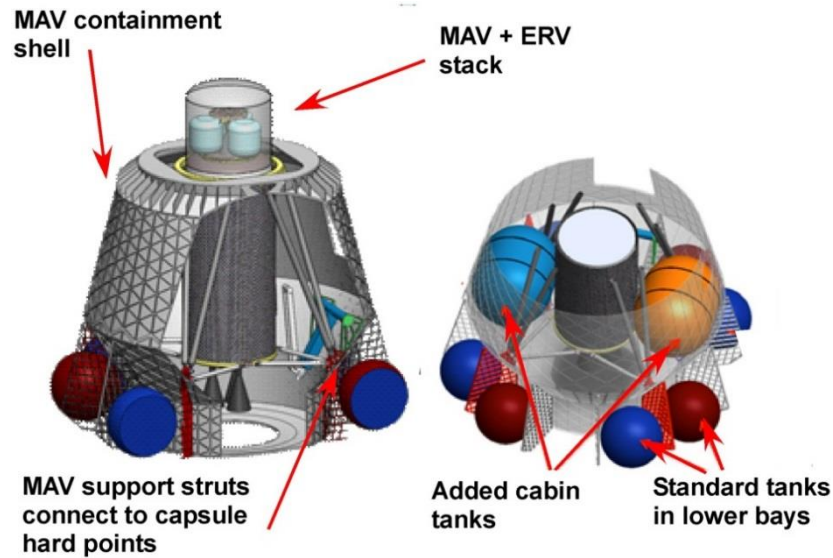
0. Red Dragon is modified to carry required hardware
 - Mars Ascent Vehicle (MAV)
 - Earth Return Vehicle (ERV)
 - Mission support hardware
 - Arm to transfer a sample from a previous rover mission (i.e. 2020 rover) to the ERV
1. Falcon Heavy launches Red Dragon to Mars
2. Red Dragon performs lifting trajectory
Entry, Descent, and Landing (EDL) with Supersonic Retro Propulsion
3. & 4. Mars Ascent Vehicle (MAV) & Earth Return Vehicle (ERV) launches towards Earth
5. ERV enters High Earth Orbit, at lunar distance, but inclined to Earth-Moon plane
6. & 7. Earth launched capsule performs rendezvous, recovers sample container, and returns to Earth

Red Dragon MSR System Elements

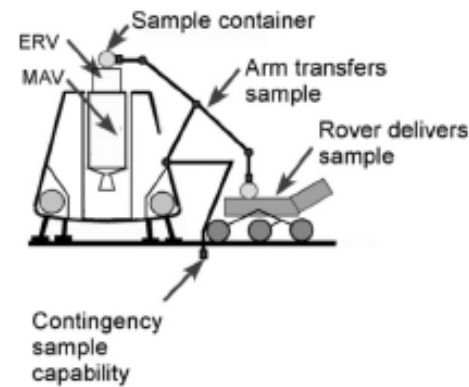
a simpler and, by extension, less costly, commercial approach by comparison



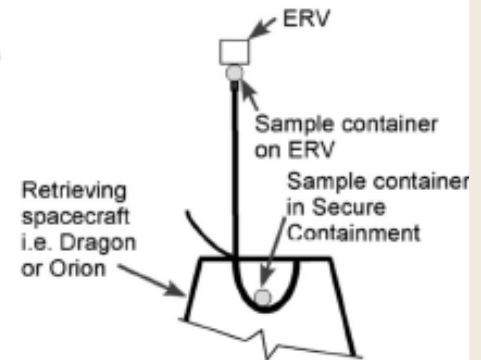
Supported by Engineering Analyses



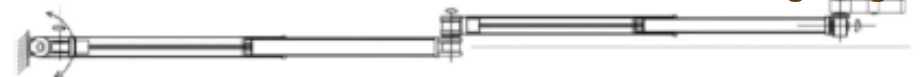
HERE



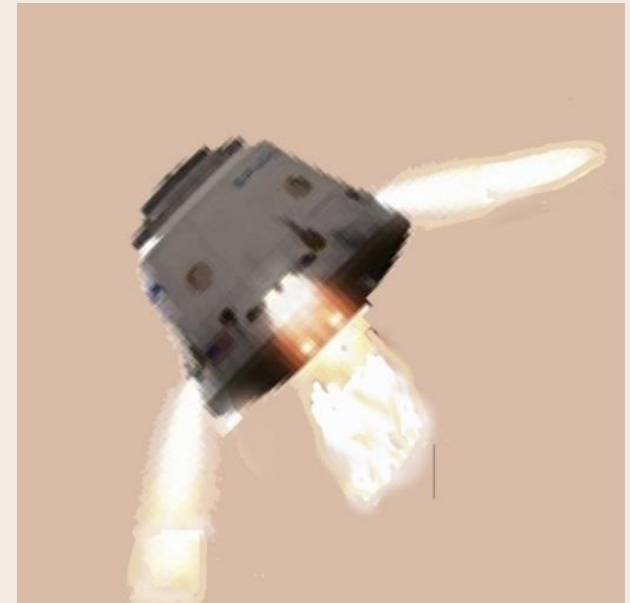
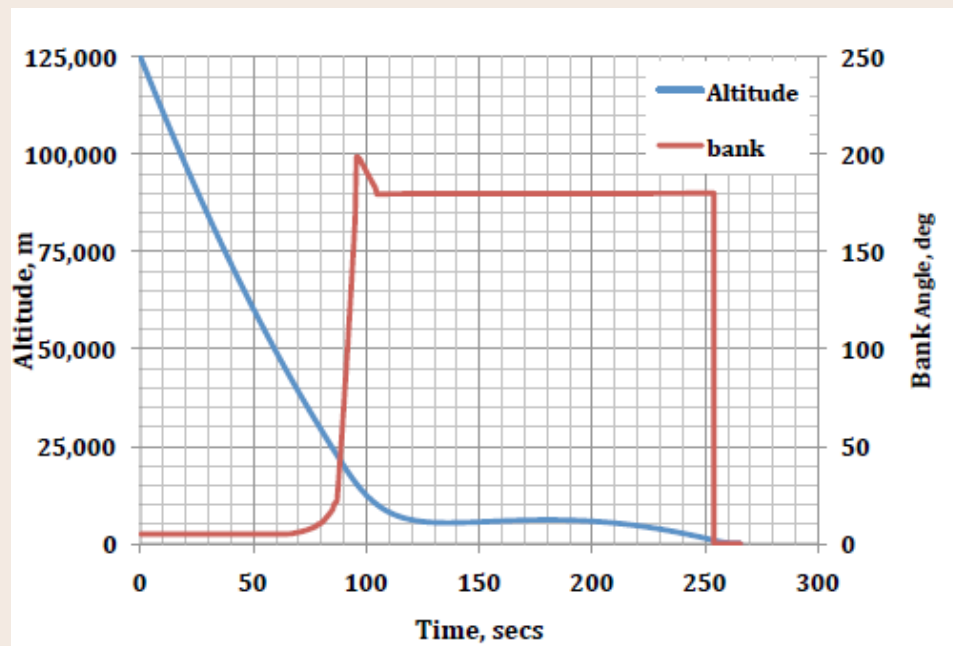
Rover to Earth Return Vehicle (ERV) while in Red Dragon



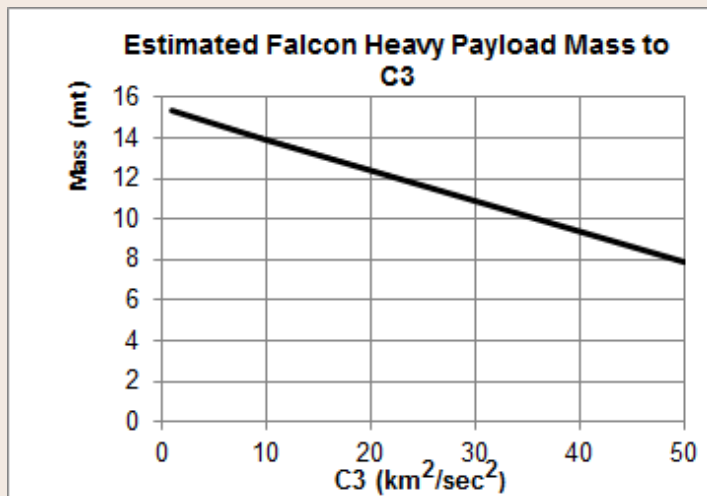
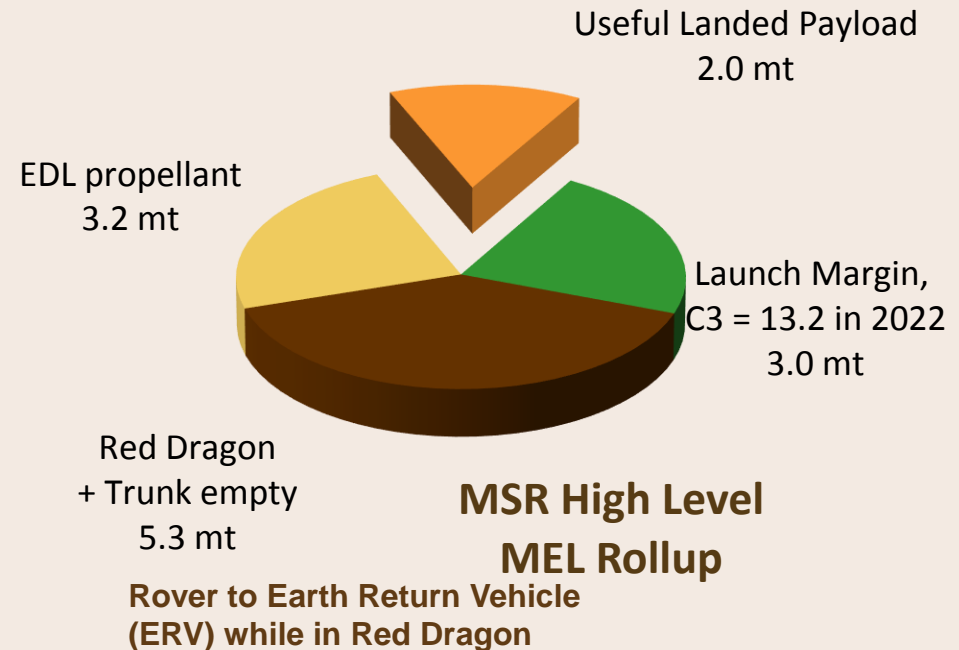
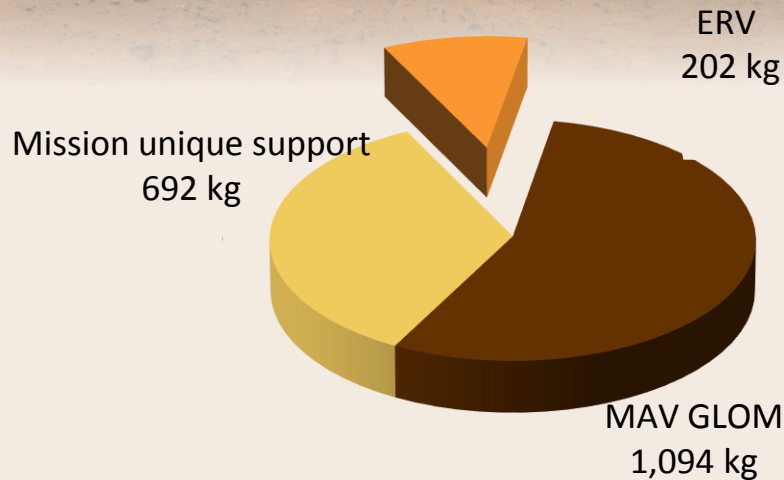
ERV to retrieval vehicle i.e. an Earth orbiting Dragon



Supported by Engineering Analyses



Payload Masses Determined



Tito, D. A., et al, 2013

- Landing Altitudes between -4 km and 0 km, Mars datum, change results by < 5%.
- Landing Seasons between Ls = 270 and 180, change results by < 5%



IceDragon Mission Concept Example

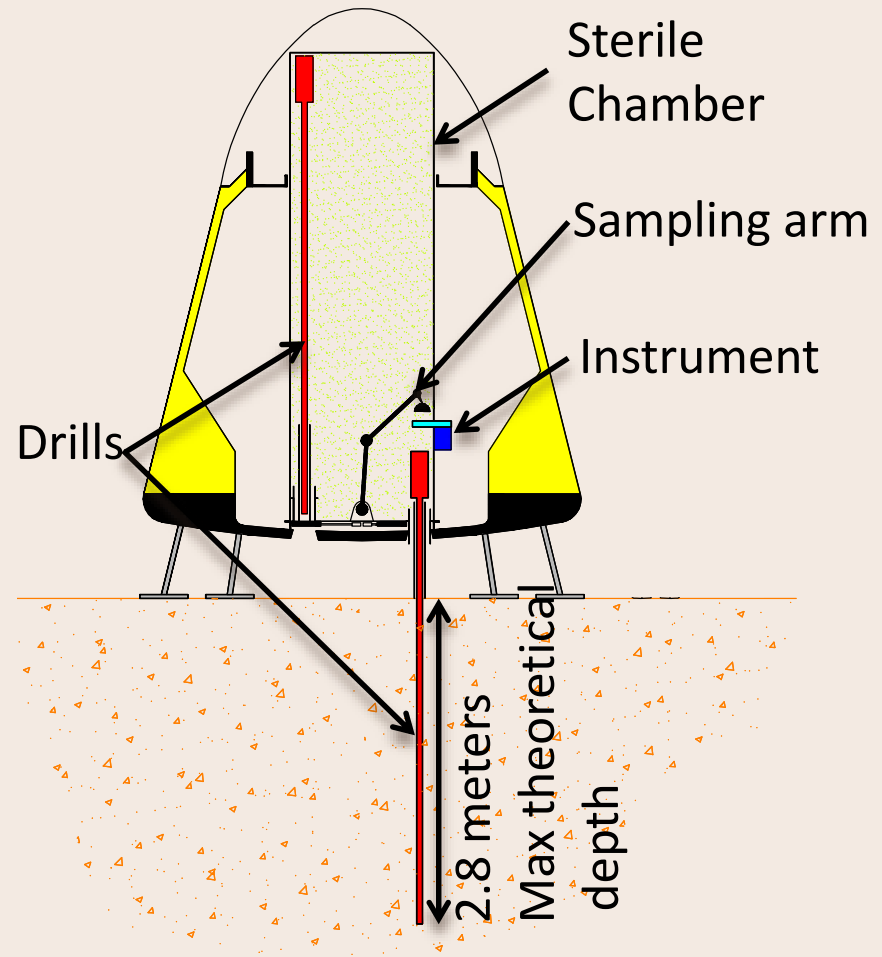
A wide-angle photograph of the Martian surface, showing a vast, flat, reddish-brown landscape with low, rolling hills in the distance under a hazy, orange-tinted sky.

IceDragon Mission – Mission Goals

- Access near surface ice or water deposits
- Look for biohazards to human explorers – not only is there life, but is that life potentially harmful to humans
- Demonstrate *In-Situ* Resource Utilization (ISRU)

IceDragon Mission – Drills stay interior

Two drills are housed within a sterile chamber. Instruments are mounted around the circumference of the chamber with sample ports extending inside. A robotic sampling arm moves cuttings from the drill to the instrument ports.



IceDragon – Drills deploy exterior

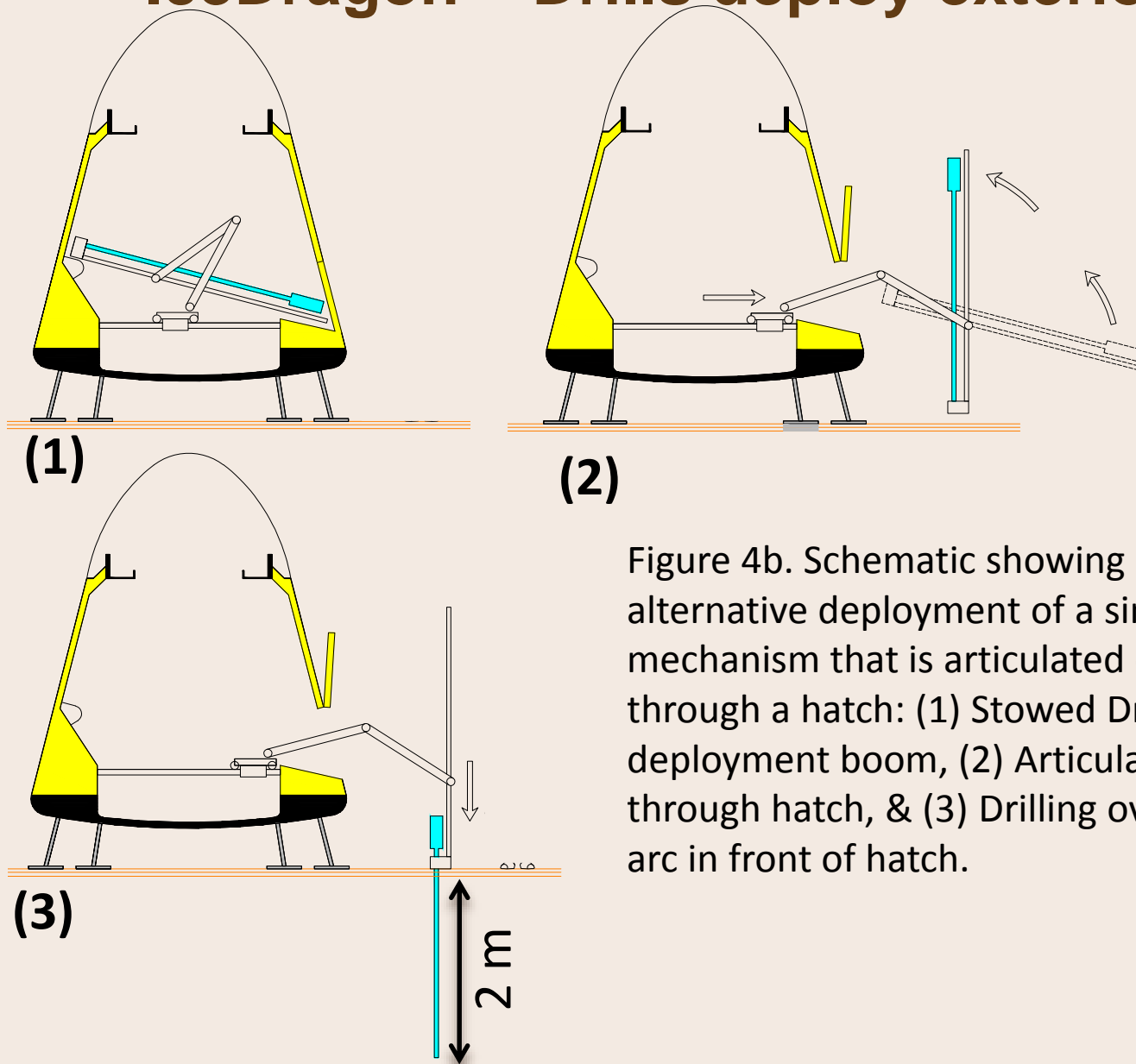


Figure 4b. Schematic showing an alternative deployment of a single drill mechanism that is articulated out through a hatch: (1) Stowed Drill & deployment boom, (2) Articulate through hatch, & (3) Drilling over an arc in front of hatch.

Additional Reading


Red Dragon
Mars Sample Return

*An Efficient Approach for Mars Sample
Return Using Emerging Commercial
Capabilities*

J. L. Heldmann, et al. “Midlatitude Ice-Rich Ground on Mars as a Target in the Search for Evidence of Life and for *in situ* Resource Utilization on Human Missions”, *Astrobiology* Vol. 14, No. 2, 2014

Team Project 2 Brainstorming

- What kind of payloads will be needed to implement the activities proposed within Team Project 2
- Where will the payloads have to be deployed?
 - Orbit, then maybe Red Dragon not needed or maybe use the trunk
 - Surface co-ordinate with human landing sites
- What capabilities are needed from Red Dragon?
- Can payload delivery services fit utilize Commercial Space Transportation or Commercial Space Services?

A wide-angle photograph of the Martian surface, showing a vast, flat, reddish-brown landscape with low, rolling hills in the distance under a hazy, orange-tinted sky.

Wrap-up

- We have seen the development of Commercial Space Transportation Services in LEO.
- We have looked plans and capabilities of commercial providers beyond LEO.
- We have seen examples of how the products of at least one commercial provider can be applied to Mars Exploration
- We have brainstormed concerning applications of at least one commercial provided to Team Project 2.